eRD12 Progress Report - Status Update on Polarimeter, Luminosity Monitor and Low Q^2-Tagger for Electron Beam (June 2015)

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This document describes the progress made since the last January 2015 report [1, 2] on the polarimeter, luminosity monitor and low Q^2-tagger projects and the general integration within the interaction region (IR). More information can be found in the eRHIC design study report [3]

1 Overall Progress Summary

Progress has been made since the last report. The last report listed four points of topic to be studied in this funding period, which are repeated here:

1. Further develop and study the low Q^2-Tagger design and performance
2. Further develop and study the Roman Pot design and performance
3. Develop and integrate a design for the luminosity monitoring system into the IR simulation
4. Develop and integrate a design for the electron polarimetry into the IR simulation

Additionally, further software development on the eicsmear package [4] has been achieved, expanding on the previously available tools. The progress towards completing each item will be discussed in more detail below.

1.1 eicsmear package software updates

Further development of the eicsmear software package [4] has been done in order to expand on the software tools available to the group. The development has been focused on the BuildTree module. This module reads in ASCII files from an assortment of different Monte Carlo event generators and produces ROOT [5] TTrees which are standardized in format and typically used in further analysis. The expansion of the module gives the user the ability to smear the x, y, and z position of the event vertex of the collision given a distribution (currently can choose either uniform or Gaussian distribution). Secondly, the user also now has the ability to feed in a crossing angle and an angular beam spread arising from beam emittance to the collision. These parameters can be fed in as arguments to the BuildTree() function. This is essential if one wants to study full collisions inside the IR simulation. This expansion is used in the latest round of simulations.

Additionally, the code was modified so the user can also read in ASCII files directly to the EicRoot simulation module while applying the smeared vertex position, crossing angle, and angular beam divergence. Some tips and instructions for running simulations in EicRoot can be found on the EicRoot wikipage [6].

1.2 Further develop and study the low Q^2-Tagger design and performance

Significant progress was made during the last review period on the development of the low Q^2-tagger concept and integration into the simulation. To briefly summarize, the detector concept is of a compact detector consisting of two tracking layers (for scattering angle reconstruction) in front on a small electromagnetic calorimeter for the measurement of the electron energy. The detector is placed on the outgoing electron beam at approximately 15 meters (after the bending dipole and right before a set a quad magnets). The detector is placed about 2cm away from the nominal beam, corresponding to roughly 10σ of the expected beam spread. More details can be found in the previous report [1, 2]. In this report we focus on the work done since that report.

More realistic simulations are performed on the current design of the detector. Previously, simulations were focused on acceptance studies and so where done with electrons being thrown over all reasonable phase space. The current round of studies feeds in PYTHIA generated events (20x250 GeV ep collisions) to the EicRoot simulation. The new tools allowing event vertex smearing and beam crossing angle are utilized in this simulation. Also a third tracking layer is added to the design to allow rudimentary track reconstruction of the electrons. Additionally, the previous tracking study used pure Monte Carlo hit information, which are perfectly known, for the rudimentary scattering angle reconstruction algorithm, as well as using the thrown electron energy rather than a reconstructed energy from the calorimeter. Now the simulation has been expanded to be more realistic and accounts for digitization and cluster reconstruction steps in the simulation. Fig. 1

shows the updated detector configuration as installed in the simulation. The yellow planes represent the tracking layers, with the blue box the calorimeter. The red boxes represent hits in the detector.

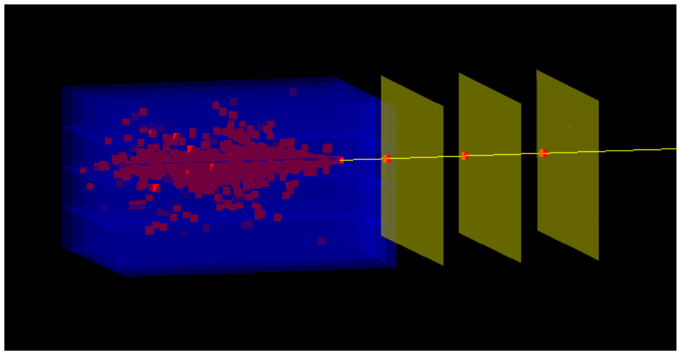

Figure 1: The low Q^2-tagger implemented in the EicRoot simulation.

The improved simulations are used to study the expected energy resolution of the calorimeter of the detector. The electron's energy can only be accurately measured if the hit occurs far enough away from the edge of the detector. This is a very important point, as many of the electrons that hit the detector will be close to this edge. The current round of simulation focuses on studying the impact of this effect, the needed fiducial cuts of the electrons, and the associated loss of statistics because of this effect. It can be considered to remove the calorimeter and instead replace it with more tracking layers if the studies show that this design will not give access to the necessary physics measurements. The material of the calorimeter has been carefully chosen in this round to yield a detector with a Moliere radius as small as possible. $PbW0_4$ was chosen as it has about a 2cm Moliere radius.

Fig. 2 shows the energy resolution of the calorimeter integrated over all electrons that hit the detector. As can be seen, the reconstructed energy (E_{reco}) is always less than the true electron energy (E_{mc}). This indicates that nearly all electrons hit close enough to the edge of the detector that some fraction of the energy is lost. But it looks as though there is a significant peak from electrons that are reconstructed within 10% of the true energy. The dependence of this resolution on the kinematics of the electron is shown in Figs. 3 and 4. The figure shows two-dimensional histograms of electron scattering angle vs energy in bins of energy resolution. The plots have been divided by the thrown distribution so that the plots illustrate the expected acceptance of electrons that contribute to a particular energy resolution on the z axis (color palette). The only difference between Figs. 3 and 4 is that Fig. 3 shows a limited range in resolution bins up to 16%, where as Fig. 4 shows up to a resolution of 50%.

The true distribution of scattered electrons from PYTHIA is shown in Fig. 5. The yield scale has been adjusted to denote the per event yield. Note that the electron beam direction corresponds to the $\theta = 10$mrad due to the 10mrad crossing angle of the beams,

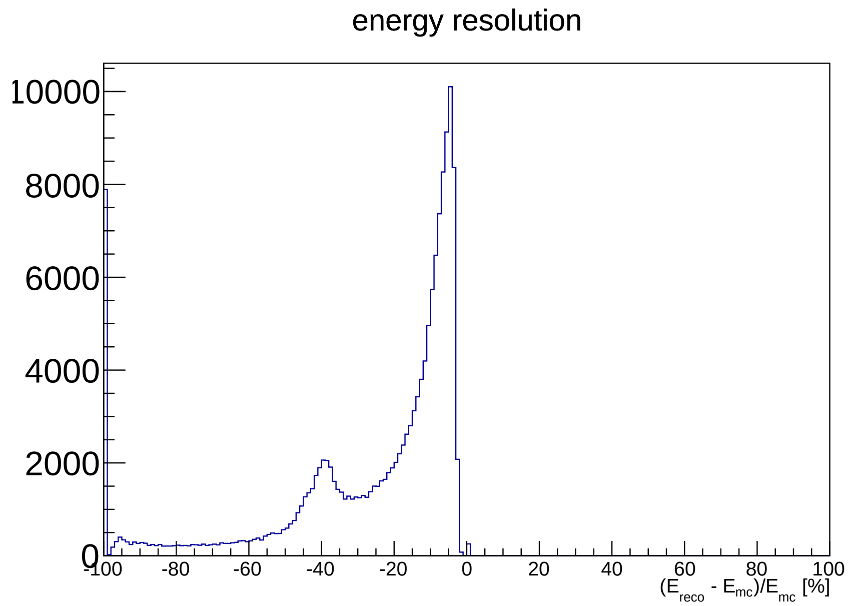

Figure 2: The energy resolution of the calorimeter of the current low Q^2-tagger design integrated over all electrons from a PYTHIA simulation.

so a $\theta = 10$mrad in reality corresponds to a true scattering angle of zero from the actual physics process.

1.3 Further develop and study the Roman Pot design and performance

No major progress has been made in the Roman Pot design since the January 2015 review. It is being considered to add numerous stations, including one immediately after the main detector and before the first beam line magnet to reclaim lost acceptance of scattered protons at high t, see [1] for details. Discussions are also ongoing with C-AD to possibly move back the beam line magnets to give more room to a Roman Pot station. These details still need to be worked out.

1.4 Develop and integrate a design for the luminosity monitoring system into the IR simulation

It is planned to use the well known $ep \to ep\gamma$ Bremsstrahlung process for the luminosity measurement. Much progress has been made in the development and integration of a luminosity monitoring system into the IR simulation. An initial concept and design has been put in and acceptance studies are ongoing. We very closely follow the design of the ZEUS experiment at HERA-II [7]. A picture of the setup in the simulation is shown in

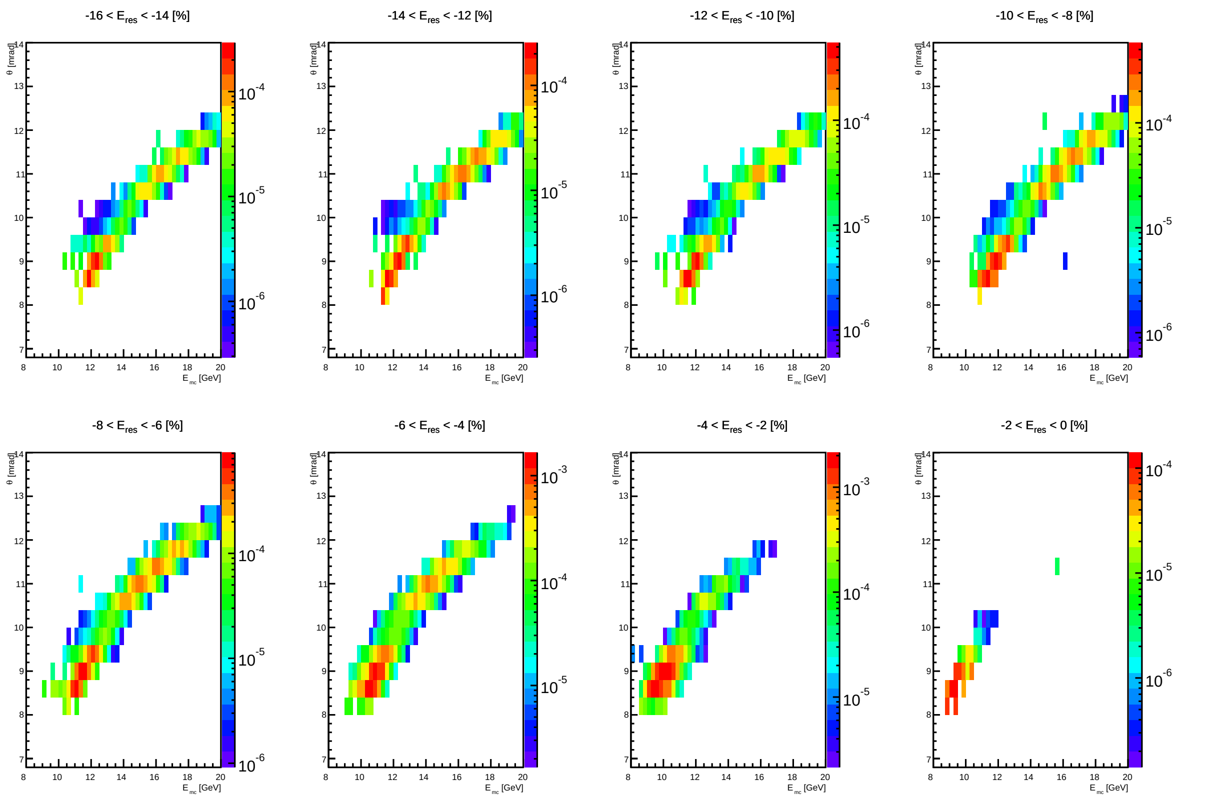

Figure 3: The acceptance in the scattering angle and energy of an electron (thrown from PYTHIA) in bins of 2% energy resolution, mapping out the phase space with the highest resolution. Note that the angle reported has been subtracted from 180^0, since the electron travels in the negative z direction in reality the angle should be in the other direction.

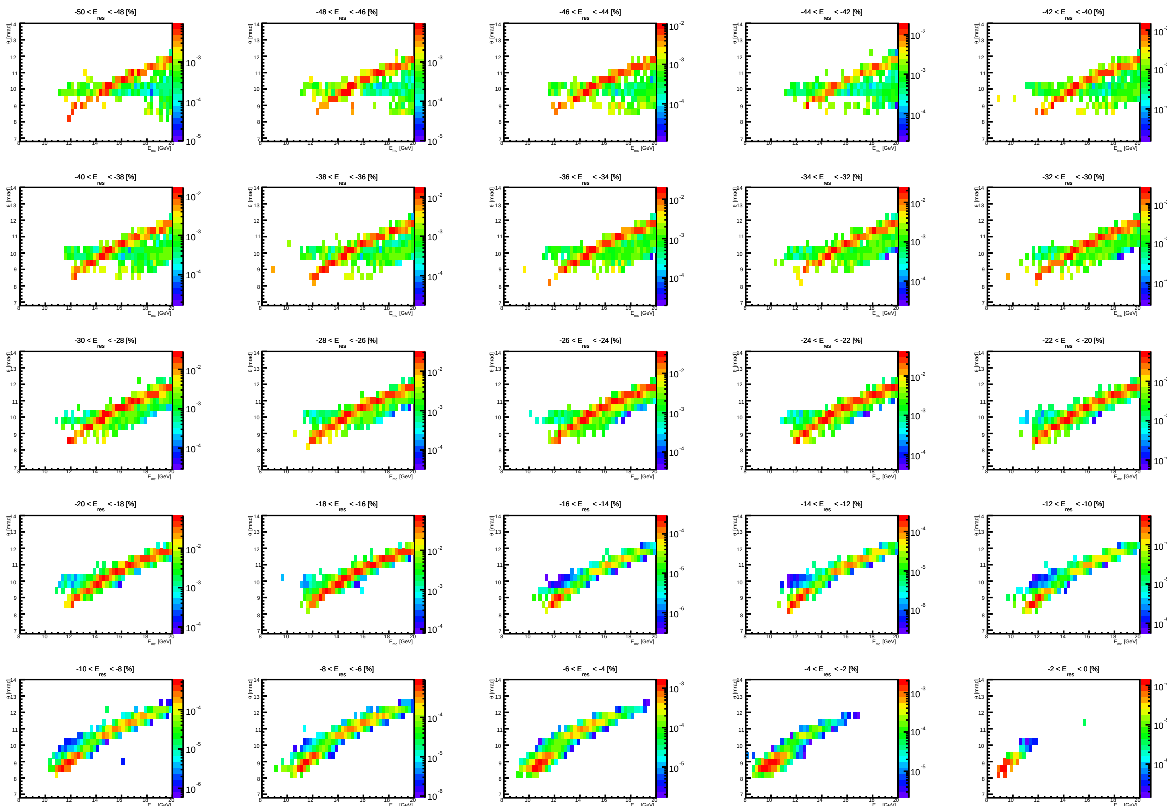

Figure 4: The acceptance in the scattering angle and energy of an electron (thrown from PYTHIA) in bins of 2% energy resolution, mapping out the phase space with the highest resolution. Note that the angle reported has been subtracted from 180^0, since the electron travels in the negative z direction in reality the angle should be in the other direction.

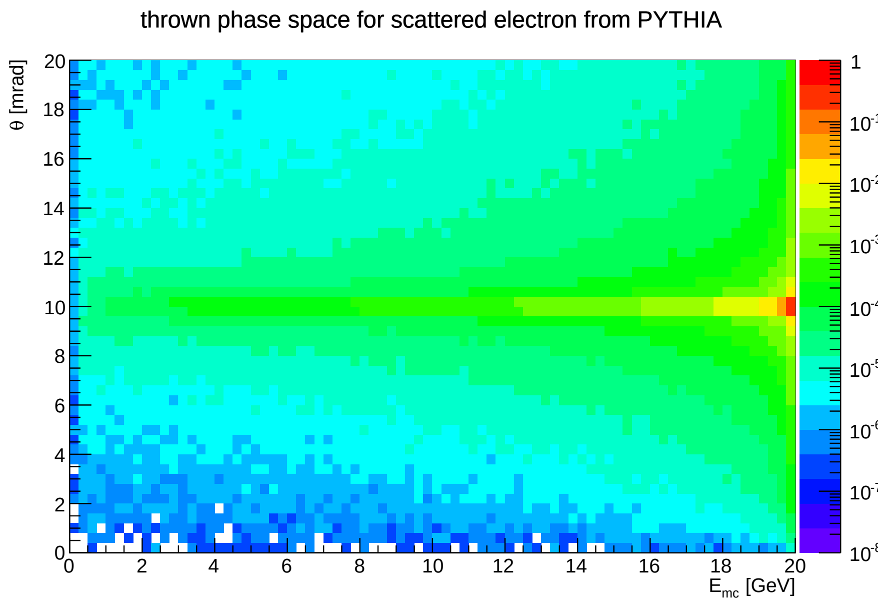

Figure 5: The phase space of scattered electrons from the PYTHIA simulation in scattering angle (θ) and energy space.

Fig. 6. The main features are the addition of a photon transport line with a converter end cap, a dipole magnet for a pair spectrometer, and a triplet of electromagnetic calorimeters. The specific strength of the dipole magnet, thickness of the converted end cap, and the spacing and placement of the calorimeters still needs to be determined. Some reasonable values were chosen as a starting point.

The photon transport line is placed in the beam line where the electron beam bends away at roughly -15m down the beam line in the outgoing electron direction. This is fixed and is more or less the only place to fit the line. The length of the photon transport line is roughly another 15m, and the line ends with a converter end cap. This end cap will convert some fraction of the Bremsstrahlung photons, depending on the thickness. The requirement of the thickness still needs to be determined, as this is dependent on the delivered luminosity and the timing capability of the calorimeters and the DAQ system. The addition of the converter is desired, in part, to reduce the rate of photons into the central calorimeter.

After the converter end cap is a dipole magnet with the field oriented along the x-axis, which will bend and separate the electron-positron pair in the vertical (y-axis) direction. Another 15 meters down is the triplet of calorimeters. A central calorimeter placed along the beam axis to capture Bremsstrahlung photons that have not converted in the end cap. The rate in this calorimeter will be high (and so gets lots of statistics very quickly), but will

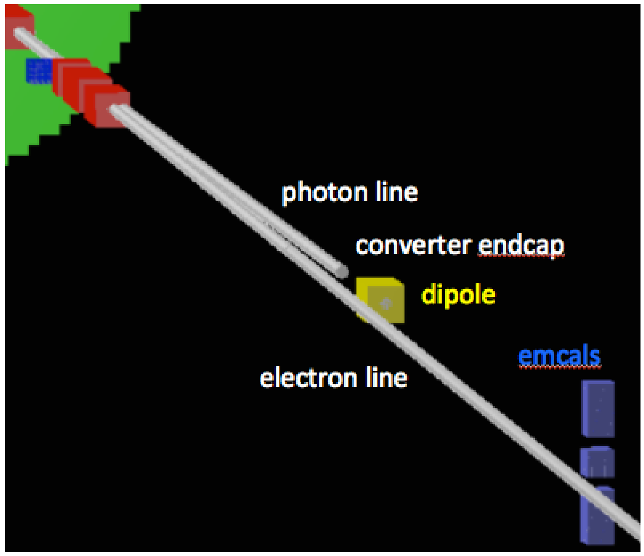

Figure 6: A picture of the luminosity monitor setup in the EicRoot simulation.

suffer from synchrotron radiation background. The upper and lower calorimeters placed directly above and below the central calorimeter in the vertical direction will capture the electron-positron pair from the photons that convert in the end cap. The hit rate will be significantly reduced in the upper and lower calorimeters compared to the central calorimeter, but has the added benefit that they will be outside the plane of the synchrotron radiation. This setup allows for two independent measurements of the luminosity with different backgrounds, offering an important systematic cross-check. This method was employed very successfully at ZEUS at HERA [7].

Effort has been expended and discussions are ongoing with Brett Parker of the BNL magnet division to ensure that we have the room for the photon line in the current design. To determine the required angular aperture, we have studied the expected Bremsstrahlung photon emission of $ep \to ep\gamma$ from the Monte Carlo generator DJANGOH, as well as from a simple Monte Carlo simulation producing photons by the Bethe-Heitler calculation []. Results on the angular distribution are similar, where the energy distributions are significantly different. This does not affect the acceptance studies at this moment. The point of this simulation at the moment is to show that the expected scattering angle of the Bremsstrahlung photons is small and is negligible compared to the expected variation of scattering angle due to beam optics.

From the beam optics requirements detailed in Table 3-1 of [3], we can calculate the angular beam divergence, which will smear the scattering angle from the physics process. Fig. 7 shows a summary of the calculation of the angular beam divergence for ep and eAu collisions at different electron beam energies (the proton/ion beam is always considered at top energy of 250 and 100 GeV respectively). For top energy ep collisions, we expect an angular beam divergence with an RMS of 0.1mrad. The typical scattering angle of the photon from the physics process is expected to be less than 0.03mrad, and so is nearly negligible in comparison.

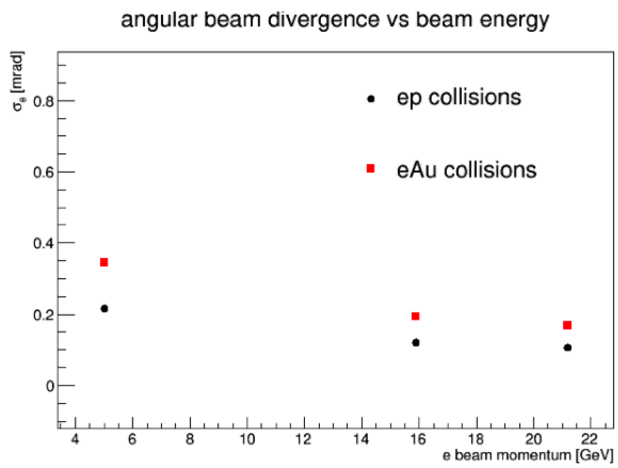

Figure 7: A plot of the expected RMS of beam divergence calculated at different electron beam energies for ep and eAu collisions given the planned beam optics quoted in Table 3-1 of [3].

Additionally we studied how the acceptance needs are changed by moving the beam collision point utilizing the newly developed tools in the eicsmear package described in Section 1.1. The DJANGOH simulations are fed through the BuildTree module adding a z vertex smearing flat with a width of 5cm, accounting for the 10mrad crossing angle, and the 0.1mrad angular beam divergence. Then an additional uniform smearing with a width of 1cm is applied to the x and y vertex positions. Comparing to the simulation with no x and y vertex smearing (that is all from (0,0)), the addition of the 1cm width uniform smearing results in a smearing of angular spread of Bremsstrahlung photons. The effect is shown in Fig. 8.

Fig. 9 shows a schematic of the current IR design with major components to scale. A ±4mrad cone is drawn to give a sense of the available space we have for the photons. This ± 4mrad is an overestimate of what we should need in reality, as evidenced by the simulations and theoretical calculations and planned beam optics.

1.5 Develop and integrate a design for the electron polarimetry into the IR simulation

No major progress has been made in the development of the electron polarimetry. Discussions have been initiated in finding a suitable place for the polarimeter with C-AD. It is

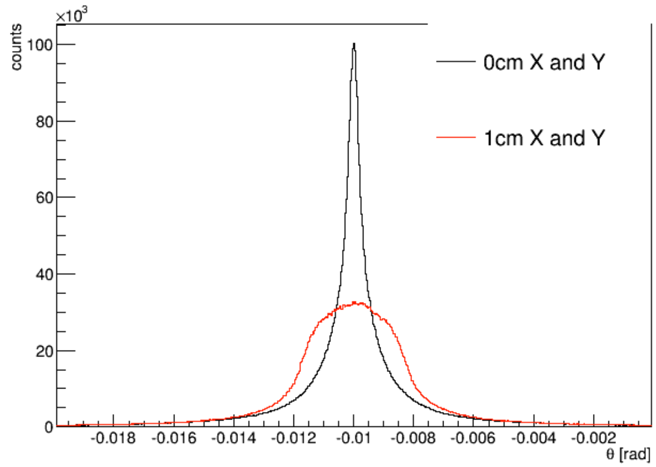

Figure 8: A plot showing the angular spread of Bremsstrahlung photons from a DJANGOH simulation of ep→epγ folding in effects of vertex smearing and beam optics. The black line shows the scattering angle distribution for a simulation with no smearing of x and y position of vertex, red shows the same distribution with an additional uniform smearing of the x and y position of the vertex of 1cm width.

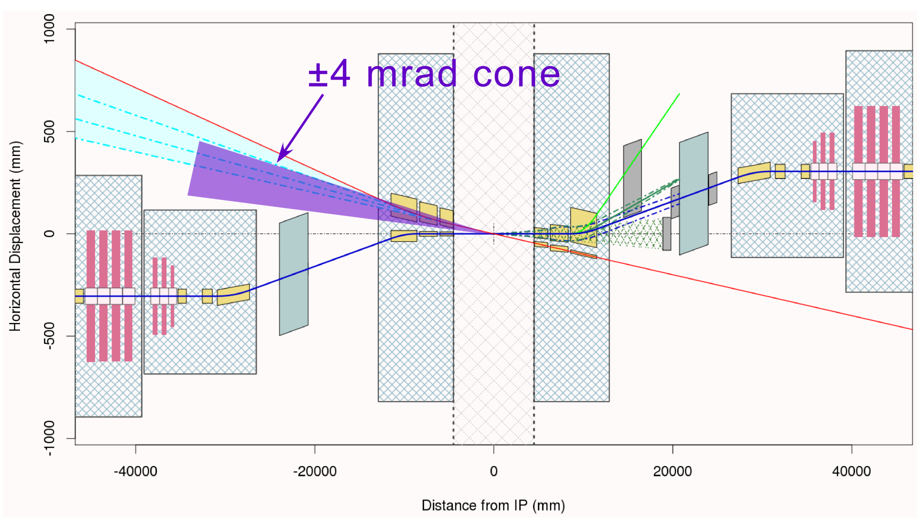

Figure 9: A schematic of the IR region with a cone of ±4mrad illustrating how much space is realistically available for the photon transport line.

quite probable that the polarimeter system will not be able to be integrated into the IR, but will have to be installed elsewhere, possibly in another IP hall.

2 Towards the next review

The main subject for the efforts for the next 6 months time period is on the electron polarimetery design. A suitable location on the ring must be found and an initial design of the components needs to be worked out, as well as some estimates of expected backgrounds.

The other components of the R&D effort (low Q^2-tagger, lumi monitor, roman pots) have been suitably developed, giving the initial concept and location and some acceptance studies. Some work on estimating expected background contributions for the various systems can be done.

3 Manpower

This section lists the available manpower for the project.

- Richard Petti (BNL physics) Post-doc funded through the R&D: supervised by Elke-Caroline Aschenauer, 90% FTE.
- Hubert Spiesberger: 20% FTE, working on a polarized ep generator for lumi measurement

The following members contribute significantly to this specific R&D project, but the percent FTE quoted is for overall eRHIC development and not specifically for the current R&D effort described in this report. Many components are intimately linked, such as the specific machine design and the placement of various detector systems. As such it is difficult to give an estimate of time spent specifically on this project.

- Elke-Caroline Aschenauer (BNL physics): 50% FTE eRHIC overall
- Alexander Kiselev (BNL physics): 100% FTE on eRHIC detector and software development
- Vladimir Litvinenko (BNL C-AD): 50% FTE overall eRHIC
- Brett Parker (BNL magnet division): 50% FTE overall eRHIC
- Vadim Ptitsyn (BNL C-AD): 50% FTE overall eRHIC
- William Schmidke (BNL physics): 10% FTE on this project
- Dejan Trbojevic (BNL C-AD): 50% FTE overal eRHIC

References

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[6] https://wiki.bnl.gov/eic/index.php/Eicroot

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